POSTAL BOOK PACKAGE 2025

MECHANICAL ENGINEERING

CONVENTIONAL Practice Sets

CONTENTS

POWER PLANT ENGINEERING

3
CHAPTER

Analysis of Steam Cycles

Practice Questions : Level-I

Q.1 In a steam power plant operating on the Rankine cycle, steam enters the turbine at 4 MPa, 350°C and exists at a pressure of 15 kPa. Then it enters the condenser and exists as saturated water. Next, a pump feeds back the water to the boiler. The adiabatic efficiency of the turbine is 90%. The thermodynamic states of water and steam are given in the table.

State	h (kJkg^{-1})		s (kJkg^{-1}K^{-1})		v (m^{3}kg^{-1})	
Steam : 4 MPa, 350°C	3092.5		6.5821		0.06645	
Water : 15 kPa	h_f	h_g	s_f	s_g	v_f	v_g
	225.94	2599.1	0.7549	8.0085	0.001014	10.02

h is specific enthalpy, s is specific entropy and v the specific volume; subscript f and g denote saturated liquid state and saturated vapour state.
What is the net work output of the cycle?

Solution:

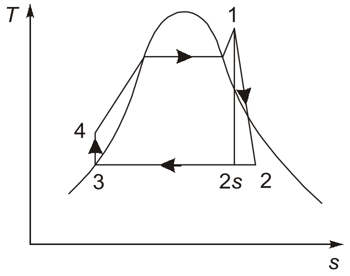
Given data: $T_1 = 350°C$; $p_2 = p_3 = 15$ kPa; $\eta_T = 90\% = 0.90$; $p_1 = p_4 = 4$ MPa $= 4000$ kPa

From given saturated steam table at

$p_1 = 4$ MPa, $T_1 = 350°C$

we get, $h_1 = 3092.5$ kJ/kg

$s_1 = 6.5821$ kJ/kg/K



From given saturated steam table (pressure based)

$h_f = h_3 = 226.95$ kJ/kg

$h_g = 2599.1$ kJ/kg

$s_f = 0.7549$ kJ/kgK

$s_g = 8.0085$ kJ/kgK

$v_f = v_3 = 0.001014$ m^{3}kg

$s_1 = s_{2s} = s_f + x_{2s}(s_g - s_f)$

$6.5821 = 0.7549 + x_{2s}(8.0085 - 0.7549)$

$6.5821 = 0.7549 + 7.2536\, x_{2s}$

or $7.2536\, x_{2s} = 5.8272$

or $x_{2s} = 0.8033$

$h_{2s} = h_f + x_{2s}(h_g - h_f)$

$= 226.95 + 0.8033\,(2599.1 - 226.95)$

$= 226.95 + 1905.54 = 2132.49$ kJ/kg

$$\eta_T = \frac{(\Delta h)_{\text{act}}}{(\Delta h)_{\text{Isen}}} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

$$0.90 = \frac{3092.5 - h_2}{3092.5 - 2132.49}$$

$$0.90 = \frac{3092.5 - h_2}{960.01}$$

or $960.01 \times 0.90 = 3092.5 - h_2$

or $864 = 3092.5 - h_2$

or $h_2 = 2228.5$ kJ/kg

Turbine work, $w_T = h_1 - h_2 = 3092.5 - 2228.5 = 864$ kJ/kg

Pump work, $w_P = v_3\,(p_1 - p_2)$ kJ/kg

where v_3 in m^3/kg and p_1 and p_2 in kPa

$\therefore$ $w_P = 0.001014\,(4000 - 15) = 4.04$ kJ/kg

Net work output of the cycle,

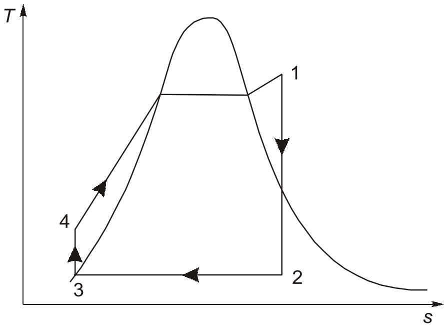
$$w_{\text{net}} = w_T - w_P = 864 - 4.04 = 859.96 \text{ kJ/kg}$$

Q.2 In a steam power plant operating on Rankine cycle, steam enters the turbine with a velocity of 500 m/s at 5 MPa, 400°C. and exit at a pressure of 10 kPa with negligible velocity. The heat rejected by the condensing steam to the cooling water is 2000 kJ/kg. The pump feeds back water to the boiler with work input of 5 kJ/kg. Find

(i) Thermal efficiency of the cycle. (ii) Moisture content of steam at turbine exit.

State	h (kJ/kg)		s (kJ/kgK)	
Steam, 5 MPa 400°C	3100		6.581	
Water (10 kPa)	h_f	h_g	s_f	s_g
	225	2600	0.755	8.01

Solution:



Given: $h_1 = 3100$ kJ/kg, $V_1 = 500$ m/s, $h_3 = 225$ kJ/kg, $h_4 = h_3 + W_P$,

$\Rightarrow$ $h_4 = 230$ kJ/kg

Heat supplied to steam in boiler, $Q_S = h_1 - h_4 = 2870$ kJ/kg

Heat rejected by steam in condenser $= Q_R = 2000$ kJ/kg

First law of thermodynamics

$$\oint \delta Q = \oint \delta W$$

$$Q_S - Q_R = W_T - W_P$$

$\Rightarrow$ $W_T = Q_A - Q_R + W_P = 2870 - 2000 + 5 = 875$ kJ/kg

1. Thermal efficiency of cycle $= \dfrac{W_T - W_P}{Q_S} = \left(\dfrac{875 - 5}{2870}\right) = 30.31\%$

2. $$W_T = \left(h_1 + \frac{V_1^2}{2}\right) - \left(h_2 + \frac{V_2^2}{2}\right) \qquad V_2 \to O$$

$$875 = 3100 + \frac{(500)^2}{2000} - h_2$$

$\Rightarrow$ $h_2 = 2350$

$$h_2 = h_f + x_2\, h_{fg}$$

$$2350 = 225 + x_2(2600 - 225)$$

$$x_2 = 0.894$$

$\Rightarrow$ Moisture content $= (1 - x_2) \times 100 = (1 - 0.894) \times 100 = 10.53\%$

Q.3 In a BWR type nuclear reactor, the heat of nuclear fission is transferred to water. In a reactor, water comes out of the reactor as saturated vapour at 72 bar. The steam flows through a turbine and exhausts at 0.08 bar to a condenser. The water leaves the condenser at 0.08 bar and 40°C (h = 176.5 kJ/kg). The liquid water is again pumped through a pump to the nuclear reactor. Isentropic efficiency of the turbine is 70%. The plant has a capacity of 750 MW. Calculate the mass flow rate of steam circulated and the rate of heat generation.

Properties of steam: p = 0.08 bar: h_f = 173.9 kJ/kg, h_{fg} = 2403.2 kJ/kg
s_f = 0.5926 kJ/kgK, s_{fg} = 7.6370 kJ/kg K, At 72 bar : h_g = 2770.9 kJ/kg, s_g = 5.8019 kJ/kg K

Solution:

Given data: $\eta_t = 0.7$; Power = 750 MW; h_{g1} = 2770.9 kJ/kg; s_{g1} = 5.8019 kJ/K;
h_f = 173.9; kJ/kg; h_{fg} = 2403.2 kJ/kg; s_f = 0.5926 kJ/kgK; s_{fg} = 7.6370 kJ/kgK;

$$s_1 = s_2$$

$$\Rightarrow \quad s_{g1} = s_{f2} + x \cdot s_{fg2}$$

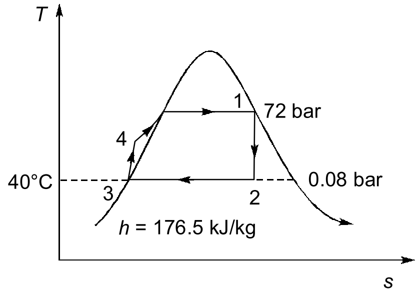
$$\Rightarrow \quad 5.8019 = 0.5926 + x \times 7.6370$$

$$\Rightarrow \quad x = 0.6821$$

$$h_2 = h_f + x h_{fg}$$

$$= 173.9 + 0.6821 \times 2403.2$$

$$= 1813.15 \text{ kJ/kg}$$



$$w_t = (h_1 - h_2) \times \eta_t$$

$$= (2770.9 - 1813.15) \times 0.7 = 670.4 \text{ kJ/kg}$$

Mass flow rate of steam, $\dot{m} = \dfrac{750000}{670.4} = 1118.7$ kg/s

$h_4 = h_3 = 176.5$ kJ/kg (Neglecting pump work)

Heat generated, $\dot{Q}_{gen} = \dot{m}(h_1 - h_4) = 1118.7 \times (2770.9 - 176.5) = 2902.44 \times 10^3$ kJ/s

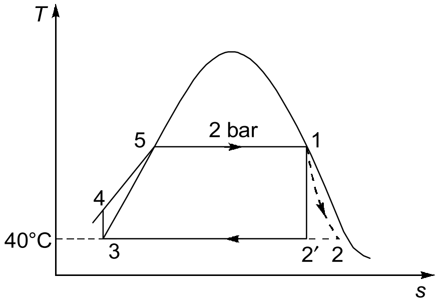
$= \mathbf{2902.44\ MW}$

Q.4 A simple steam power cycle uses solar energy for heat input. Water in the cycle enters the pump as saturated liquid at 40°C and is pumped to 2 bar. The water at this pressure evaporates in the steam generator and enters the turbine as saturated vapour. At the exit of the turbine, the condition of steam is 40°C with dryness fraction of 0.9. The flow rate is 150 kg/h. The instantaneous solar input is 0.58 kW/m^2 at a specified time. Obtain the isentropic efficiency of the turbine, net work output, cycle efficiency and the area of the solar collector needed based on the given solar input.

Following properties of steam are given:

p (bar)	T (°C)	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
		(kJ/kg)			(kJ/kgK)		
0.07375	40	167.53	2405.97	2573.5	0.572	7.686	8.258
2	120.2	504.7	2201.6	2706.3	1.530	5.597	7.127

Solution:



$$h_1 = 2706.3 \text{ kJ/kg}$$

$$h_3 = h_{f3} = 167.53$$

$$h_4 - h_3 = v dp$$

$$h_4 - 167.53 = v_f(200 - 7.375)$$

Since v_f is not given so neglecting pump work

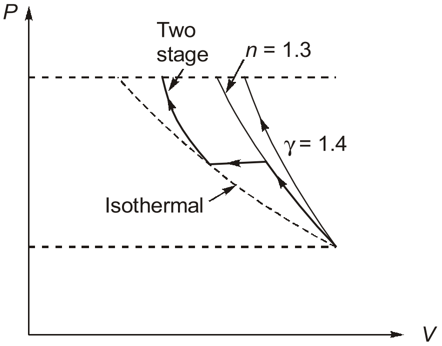
so $h_4 - h_3 \cong 0 \qquad (h_4 = h_3 = 167.53)$

Q.2 Air is compressed steadily by a reversible compressor from an inlet state of 100 kPa and 300 K to an exit pressure of 900 kPa. Determine the compressor work per unit mass for (i) Isentropic compression with $\gamma = 1.4$; (ii) Polytropic compression with $n = 1.3$; (iii) Isothermal compression and (iv) Ideal two-stage compression with intercooling with a polytropic exponent of 1.3.

Solution:

Given data: Inlet state : $p_1 = 100$ kPa; $T_1 = 300$ K; Exit state : $p_2 = 900$ kPa

(i) Isentropic compression ($\gamma = 1.4$)



$$w_C = \frac{\gamma R T_1}{\gamma - 1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

$$= \frac{1.4 \times 0.287 \times 300}{0.4}\left[\left(\frac{900}{100}\right)^{\frac{0.4}{1.4}} - 1\right]$$

$$= 263.2 \text{ kJ/kg}$$

(ii) Polytropic compression (n = 1.3)

$$w_C = \frac{nRT_1}{n-1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= \frac{1.3 \times 0.287 \times 300}{0.3}\left[\left(\frac{900}{100}\right)^{\frac{0.3}{1.3}} - 1\right] = 246.4 \text{ kJ/kg}$$

(iii) Isothermal compression,

$$w_C = RT_1 \ln\frac{p_2}{p_1} = 0.287 \times 300 \ln\left(\frac{900}{100}\right) = 189.2 \text{ kJ/kg}$$

(iv) Ideal two-stage compression with intercooling ($n = 1.3$)

$$p_i = (p_1 p_2)^{1/2} = (100 \times 900)^{1/2} = 300 \text{ kPa}$$

$$w_C = \frac{2nRT_1}{n-1}\left[\left(\frac{p_i}{p_1}\right)^{\frac{n-1}{n}} - 1\right] = \frac{2 \times 1.3 \times 0.287 \times 300}{0.3}\left[\left(\frac{300}{100}\right)^{\frac{0.3}{1.3}} - 1\right] = 215.3 \text{ kJ/kg}$$

Q.3 A centrifugal compressor running at 18000 rpm takes in air at 25°C and compresses it through a pressure ratio of 4.0 with an isentropic efficiency of 80%. Guide vane at inlet give the air an angle of pre-whirl of 20° to axial direction. The mean dia of impeller eye is 225 mm. Absolute air velocity at inlet is 130 m/s. At exit the blades are radially inclined. The slip factor is 0.9, calculate the impeller tip diameter.

Solution:

Given data: $N = 18000$ rpm; $D_1 = 225$ mm; $V_1 = 130$ m/s; $\eta_c = 80\%$; $u_1 = \dfrac{\pi D_1 N}{60} = 212.06$ m/s